A STUDY OF THE EFFECTS OF THE HEATING AND THE DRIVING CONDITIONS ON HOT-DRIVEN STRUCTURAL STEEL RIVETS

BY

ROBERT AARON HECHTMAN

B. S. in C. E., University of Washington, 1938
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AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING
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I. Synopsis

Although much information about tests of structural steel riveted joints and connections appears in the technical literature, very little is to be found about the factors which influence the quality of the rivet itself. Most of the available material concerning the effect upon the quality of the rivet of the manufacturing process, the heating for driving, the driving, and the subsequent cooling of the rivet, relates to tests made a number of years ago on plain-carbon and alloy steels of compositions no longer commonly used for structural rivets.

This investigation was planned to determine the factors which affect the mechanical properties of a driven rivet and to ascertain the extent of the influence of these factors upon these properties. Studies were made of ⅞-in. rivets of three carbon steels and of one silico-manganese steel, all driven by pneumatic hammer under driving conditions as similar as possible to those prevailing in fabricating shops and in field erections. The mechanical properties of the rivets of the various steels were regulated by controlling the conditions of heating, driving, and cooling. The ductility of the driven rivet resulting from the heating and driving conditions as applied to the four rivet steels, was determined from tension-impact tests of the driven rivet as a whole. The results of the tension-impact tests were correlated with the metallurgical conditions determining the microstructure of the rivet. Temperature recordings were made during heating and driving of some rivets. The development of the initial tension in the rivet was studied by making simultaneous measurements of the temperature and of the initial tension in rivets during

driving and subsequent cooling. The forgeability of the four kinds of steel was investigated and compared with the forging characteristics of the rivets made from the steels as observed during the driving of the rivets.

II. Acknowledgements

This thesis is submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil Engineering and has been written under the direction of W. M. Wilson, Research Professor of Structural Engineering in the Department of Civil Engineering, of which Prof. W. C. Huntington is head. It has been a part of the work of the Engineering Experiment Station, of which Dean M. L. Enger is director. Funds for this investigation have been furnished by the Office of Naval Research, U. S. Navy Department, as part of a research project directed by N. M. Newmark, Research Professor of Civil Engineering. The author is very grateful for the suggestions and comments of H. L. Walker, Head, Department of Mining and Metallurgical Engineering, and W. H. Bruckner, Research Assistant Professor of Metallurgical Engineering. The instrumentation was developed mostly by H. C. Roberts, Special Research Associate Professor of Civil Engineering. Most of the mechanical tests were made by Mr. J. E. Stallmeyer, Research Assistant in Civil Engineering, with the assistance of Mr. C. F. Zirzow. Laboratory mechanics comprised the riveting crew. The facilities of the Department of Civil Engineering were used for the mechanical testing and the laboratories of the Department of Mining and Metallurgical Engineering for the metallurgical studies.

III. Object and Scope of the Investigation

The object of this investigation was two-fold: first, to study the thermal and the mechanical behavior of the structural rivet during heating, driving, and subsequent cooling and to correlate this behavior with the metallurgical char-

acteristics and the mechanical properties of the rivet steels; and, second, to determine the effects of the heating and the driving conditions upon the mechanical and the metallurgical quality of the driven rivet. The first part of the investigation was concerned primarily with what happened in the rivet during the driving process, while the second part was directed towards determining the service which the rivet might give as a part of a structure or a ship.

The scope of the investigation may be outlined as follows:

1. The effect of the heating and the driving conditions upon the mechanical properties of the driven rivet and the correlation of these mechanical properties with the metallurgical characteristics resulting from the heating and driving conditions.
2. The suitability of fully-killed plain-carbon steel for rivets.
3. The comparative forgeability of the four rivet steels.
4. The thermal and mechanical behavior of the rivet during driving and the subsequent cooling which result in the development of the initial tension in the rivet.

This investigation was restricted by the size of the problem to a study of rivets hot-driven with pneumatic hammers. Moreover, this work has been directed more towards determining the various factors which affect the quality of the driven rivet than towards studying any of these factors intensively.

IV Driving Equipment and Tests

1. Driving Equipment.

Standard riveting equipment was used except for heating, where the control possible in a laboratory-type furnace was desirable. Two pneumatic riveting hammers were used, one No. 60 and one No. 90 size hammer. Standard high button-head dies were purchased. A portable, two-cylinder com-

pressor supplied the air pressure for driving all the rivets except those driven with the two pneumatic hammers, for which compressed air from the laboratory system was used.

The rivets for the tension-impact tests of whole rivets were driven in threaded blocks held in a driving block. The rivets for the initial tension tests were driven in a second driving block designed to weigh the tension in the rivet. The tension and the temperature of the rivet were recorded simultaneously by recording instruments. Both driving blocks were water-cooled to simulate the cooling effect of a large mass of plate around the rivet.

2. Tests.

Cooling data were obtained by recording the temperature of the rivets during and after driving. The driving time to reach finishing temperatures of 1300, 1000, and 700 Deg. F. were determined. Since the driving time might vary somewhat for different rivets, the finishing temperature of each rivet was checked by observing the color of the driven head.

The impact test at various temperatures was selected as the best means of comparing the effects of the different heating and driving conditions upon the ductility of the driven rivet. The use of the whole rivet preserved the characteristics of shape, fiber, and variation of the microstructure within the rivet. A tension-impact testing machine was built which was capable of testing the whole driven rivet.

The drop test was used to investigate the forgeability of small cylindrical specimens of the four steels at temperatures from 70 to 2300 Deg. F. A duplicate specimen was heated with each drop-test specimen and quenched to obtain the prior austenite grain size.

Tests of notched impact specimens machined from driven rivets and from the rivet steel as received, showed the effect of heating and forging upon the notch-sensitivity of the rimed steel.

Metallographic examination was made of longitudinal sections at different points in four rivets to study the variation of the microstructure within a single rivet. A number of rivets heated at various temperatures and for varying periods of time were sectioned, and their microstructure was examined.

V. Conclusions

Rivets made of four rivet steels were investigated: a rimmed steel, a semi-killed steel deoxidized with silicon, a fully-killed steel deoxidized with silicon and aluminum, and a silico-manganese steel. The results of the tests of rivets of these four steels appear to justify the conclusions which follow. Unless otherwise noted, all conclusions refer to $\frac{7}{8}$-in. diameter high button-head rivets with a 5-in. grip driven by one pneumatic hammer at an air pressure of 80 psi to a finishing temperature of approximately 1000 Deg. F. Tension-impact tests of the whole driven rivet were used to determine the transition temperature for the various heating and driving conditions.

Because this work was directed mostly towards uncovering the various factors which determine the quality of the rivet, some of the factors were not thoroughly studied. In these cases, the conclusions are necessarily tentative.

*1. Heating Conditions.**

1. The transition temperature of the rimmed steel rivets was lowered by increasing the heating temperature from 1900 and 2100 Deg. F. to 2300 Deg. F. A similar decrease in the transition temperature was produced in the rimmed steel rivets by normalizing them at 2300 Deg. F. before heating at 1900 Deg. F.

2. An increase in the heating time from 30 to 60 min. for a heating temperature of 1900 Deg. F., lowered the

*Five heating conditions were studied: 30 min. at 1900 Deg. F., 30 min. at 2100 Deg. F., 30 min. at 2300 Deg. F., 60 min. at 1900 Deg. F., and normalizing at 2300 Deg. F. and reheating 20 min. at 1900 Deg. F.

transition temperature of the rimmed steel rivets.

3. The limited number of tests of the semi-killed steel rivets indicated that the transition temperature was slightly affected by increasing the heating temperature from 1900 to 2100 Deg. F.

4. 4. No transition temperature was found for the killed steel rivets heated under the five conditions within the range of testing temperatures, some as low as -80 to -90 Deg. F., except that the rivets normalized at 2300 Deg. F. before heating showed some brittleness at the lowest testing temperature.

5. The transition temperature of the silico-manganese steel rivets was considerably lowered by increasing the heating temperature from 1900 to 2100 and 2300 Deg. F., but markedly raised by the high temperature normalizing before heating.

6. An increase in the heating time from 30 to 60 min. for a heating temperature of 1900 Deg. F. caused no change in the transition temperature of the silico-manganese steel rivets.

7. The greatest decrease in the transition temperature caused by increasing the heating temperature occurred in the rimmed steel and the silico-manganese steel rivets. The undriven rivets of these two steels exhibited the most evident inhomogeneity in their microstructure: that is, the non-uniform distribution of the sulphur and the carbon in the cross-section of the rimmed steel and the banding in the silico-manganese steel.

8. The results of the tension-impact tests of rivets heated at different temperatures indicated that the best quality of rivet could be obtained by the proper combination of the kind of steel and the heating condition.

2. Driving Conditions.

1. Varying the finishing temperature between 1300 and 700 Deg. F. did not affect the quality of the killed steel and the silico-manganese steel rivets. On the other hand, the rimmed steel rivets finished at a temperature of 700 Deg. F. were greatly inferior in quality to those finished at 1000 Deg. F.

2. The small number of tests made indicate that an increase in the intensity of the forging, either by increasing the air pressure in driving or by using two pneumatic hammers instead of one, reduced the quality of the plain-carbon steel rivets, but improved the quality of the silico-manganese steel rivets. However, more tests are required to substantiate this trend.

3. The heavier forging caused by driving with two pneumatic hammers as compared to the use of one hammer tended to develop finer grained microstructures in the manufactured head of the rivet.

3. Significance of the Microstructures.

1. The heating temperatures of 1900 to 2300 Deg. F. for a heating time of 30 min. produced widmanstatten structures in all the steels except the killed steel heated at 1900 Deg. F., although the cooling rate of the rivets through the critical temperature range was low.

2. The character of the microstructure appeared to be related to the intensity of the forging action, the structure nearer the riveting dies being fine and granular and that further from the dies being coarse and widmanstatten in type.

3. The brittle failures consistently occurred at the junction of the shank and the manufactured head where the fracture was initiated in a widmanstatten microstructure and consistently did not occur at the junction

of the shank and the driven head where the structure was fine grained and granular.

4. The transition temperature of the forged material in the rivet shank with a widmanstatten microstructure was considerably lower than the transition temperature of the unforged material in the rivets as received from the mill, the latter having a fine granular structure.

4. Comparative Forgeability of the Four Rivet Steels.

1. The resistance to forging was determined by the reduced height of small cylindrical specimens subjected to the single-blow drop test. The resistance to forging was essentially the same for the four steels at each of the testing temperatures from 70 to 2300 Deg. F. This common resistance was only slightly less at 1300 Deg. F. than it was at 70 Deg. F., but decreased linearly with an increase of temperature from 1300 to 2300 Deg. F. at a more rapid rate. The specimens tested at 2300 Deg. F. were reduced to approximately five-eighths of the height of those tested at 1300 Deg. F. and to about three-fourths of the height of those tested at 1900 Deg. F.

2. The increased forgeability of the four rivet steels as the temperature increased was reflected in a reduction of the time required to form the driven head.

3. The prior austenite grain size apparently had no significant effect upon the forgeability of the four steels. The resistance to forging was dependent principally upon the forging temperature.

5. Development of the Initial Tension in the Rivet during Driving and Subsequent Cooling.

1. Practically all the initial tension in the rivet developed

after the rivet had cooled below the lower critical temperature.

2. Driving the rivet to a finishing temperature somewhat above the lower critical temperature produced a greater initial tension than driving to, or beyond, the lower critical temperature.

3. The initial tension in the rivet was found to depend principally upon the proper driving time (or finishing temperature).

VITA

Robert Aaron Hechtman was born in Spokane, Washington, on April 22, 1911. He was graduated from the University of Washington in 1938, with the degree of Bachelor of Science in Civil Engineering. During intervals in his undergraduate study, he was employed by the Wallace Bridge and Structural Steel Company, Seattle, Washington, and the Chicago, Milwaukee, St. Paul, and Pacific Railroad, Miles City, Montana. He served as Teaching Fellow at the University of Washington while taking graduate work, for which he was granted this degree of Master of Science in Civil Engineering in 1939. In 1939, he was appointed Research Assistant on the staff of Lehigh University and, with his research work, continued his graduate study. He joined the engineering staff of Dravo Corporation, Pittsburgh, Pennsylvania, in 1941, as a Design Engineer and successively thereafter held the positions of Production Engineer, Assistant to the Superintendent, and Administrative Assistant to the Chief Estimator. In 1945, he was appointed Special Research Engineer in Civil Engineering on the staff of the University of Illinois and is presently serving in this capacity.

He was elected a Member of Tau Beta Pi in 1938 and a Member of Sigma Xi in 1940. He is an Associate Member of the American Society of Civil Engineers, an Associate Member of the American Welding Society, and a Member of the American Society for Metals.